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Industry 5.0 in SME Environments: Challenges, Opportunities, and Adoption Roadmaps

Dileshwar Kumar Sahu[1]*, Dr. Suraj Kumar Mukti [2]

[1]Research Scholar, NIT Raipur

Email ID : dilesh3009@gmail.com

[2]Associate Professor, Department of Mechanical Engineering, NIT Raipur

Email ID : Skmukti.mech@nitrr.ac.in

ABSTRACT
In Industry 5.0, the new paradigm is a movement of separation between manufacturing this is highly automated and shifting to the new model of sustainable, robust, and human-centered manufacturing which involves integrating higher levels of automation alongside human imaginative and dexterious skills. Small and medium-sized businesses (SMEs) find Industry 5.0 presents opportunities to become more competitive, personalise products, minimise environmental impact, and enhance worker welfare, however, there are more down-to-earth challenges such as lack of financing, digital skills, outdated systems, and unpredictable incentives in regulation. The paper provides the synthesis of recent literature by (1) defining the Industry 5.0 paradigm in relation to SMEs; (2) overviewing significant technological, organisational, and policy challenges and opportunities (3) deducing a structured, stage-would roadmap of its adoption that corresponds to SME constraints; and (4) finding out the practical limitations and future research directions. The paper is also meant to be a brief practical guide to the SME managers, cluster organisations and the policy makers intending to plan on transitional strategy towards Industry 5.0.
Keywords— Industry 5.0; SMEs; human-centric manufacturing; sustainability; resilience; digital transformation; adoption roadmap; barriers and enablers...

1. INTRODUCTION:

The modern world of industry is changing radically due to the accelerated development of digital technologies, the need to be sustainable, and changing socio-economic demands. Although Industrial 4.0 focused mainly on automation, cyber-physical, and efficiency driven by data, according to the recent discussions, it has weaknesses in terms of its human wellbeing, environmental sustainability, and resilience in long term [2]. Respondent Industry 5.0 has developed as the complementary paradigm that re-centres industrial development on human-centricity, sustainability and resilience making technology a facilitator and not a substitute of human creativity, and decision-making. It is especially pertinent to small and medium-sized enterprises (SMEs), which constitute the major part of the industrial economy in any economy and are essential in employment, diffusion of innovations, and economic stability of the regions.

The nature of the environment of SMEs is intrinsically unlike the large enterprises. They are usually marked with limited financial funds, limited access to modern infrastructure, smaller workforces, and informal management frames [5]. Meanwhile, SMEs have such inherent advantages as flexibility, being close to their product, and providing tailored products and services. These strengths make Industry 5.0, with its focus on personalization, flexible production, as well as collaborative human-machine systems, an easy fit. Nevertheless, the move to Industry 5.0 is not automatic and easy to move to as an SME. The introduction of these systems creates complexities in the adoption process due to lack of skills, doubt on what will be returned to the company, integration difficulties with the old systems and absence of customized implementation models.

The rationale behind the study is the lack of relevance between high-level Industry 5.0 vision and the practical issues of SMEs. The available literature is extensive on conceptual definitions, or policy level approaches, or even technology based discussions with an inherent assumption of the access to capital, expertise and structured innovation networks. The above assumptions are usually not true of SMEs especially the developing and emerging economies. Consequently, SME decision-makers have difficulties in the process of translating abstract Industry 5.0 concepts into practical strategies that can bring about tangible business value and at the same time meet the sustainability and workforce wellbeing objectives [8].

Moreover, SMEs begin to undergo the pressure of external factors on them that render Industry 5.0 implementation not only desirable but also inevitable. Customers expect more gaps and demand, regulators are stricter about their environmental and safety levels, global supply chains are more susceptible to pandemic related disruption, geopolitical warfare and weather-related incidents. In this regard, the essential pillars of Industry

5.0 such as resilience and adaptability are vital survival aspects. The SMEs, which do not adapt, will be marginalized and the ones that successfully adopt humanist digital transformation may obtain sustainable competitive advantages [4].

Although Industry 5.0 is becoming more popular, few frameworks, addressing the issues and opportunities exposed to SMEs, are clear and structured into pathways to be followed when adopting it. The existing literature tends to put SMEs under a blanket or merely reducing the size of large enterprise models without paying much attention to sector differences and situational limitations [9]. Additionally, less focus has been made on balancing between technological adoption with human and organizational levels, including workforce redesign, skills development and cultural preparedness. This distance indicates the necessity to have a systematic but elastic roadmap which SMEs can effectively execute.

To fill these gaps, this paper has provided a detailed discussion of the use of Industry 5.0 in SME setting based on three related dimensions namely, challenges, opportunities, and adoption roadmaps. The work summarized the latest scholarly literature, the policy reports, and the applied frameworks and created a coherent narrative that connected the theory with the practical. The study does not suggest complete digital transformation and instead focuses on incremental, modular, and human-based methods of adoption depending on SME capacities [6].

The main goals of this paper have four folds. First, it attempts to put the concept of Industry 5.0 in context in SME setting and specify how the concepts of Industry 5.0 contrast and develop upon Industry 4.0. Second, it was systematic in identifying the main technological, organizational, financial, and social-cultural issues facing SMEs throughout the adoption. Third, it brings out the opportunities that Industry 5.0 presents to SMEs, such as improved customization, worker satisfaction, market differentiation based on sustainability, and operational bases. Lastly, the paper suggests a stage-by-stage adoption roadmap aimed at helping the SMEs through awareness till the implementation becomes a habit with minimum risk and maximum learning.

The relevance of this research is that it is practically oriented. It is more inclusive and realistic as it focuses directly on SMEs, in connection to Industry 5.0 transitions. It is hoped that the findings will be helpful in enabling SME owners, managers, technology providers, and policymakers make sound decisions with respect to investment priorities, workforce development, and support mechanisms. Finally, the paper will prove that Industry 5.0 is no distant dream but a viable and value-generating prospect of SMEs in a strategic and gradual manner [3].

Novelty and Contribution

This work is novel in that it explicitly views the idea of Industry 5.0 through the perspective of SMEs and does not engage in conceptualizing the idea through generalized terms but instead provides practical advice based on the realities of operating a small or medium-sized enterprise. Although the current literature is mainly concerned with large-scale manufacturing systems or policy-level visions, this paper re-conceptualizes Industry 5.0 as a realistic model of transformation in SME settings with limited resources, agile and human-intensive processes.

One of the latest advanced features of this work is the combined approach to the human, technological, and sustainability issues through the prism of a single adoption. Instead of treating innovative technologies, including artificial intelligence, collaborative robots, and IoT, as isolated facilitators, the paper introduces them as the means that have to be co-designed with the abilities of the workforce, job redesign, and organizational culture. This point of view of human-technology co-evolution is especially applicable to SMEs, with employees commonly having many roles and tacit knowledge having a key part in the quality of production and innovation.

The second contribution of importance is that a stage-based Industry 5.0 adoption roadmap which is specifically designed and adjusted to SME limitations was developed. In contrast to models of linear or technology-intensive transformation, the roadmap suggested focuses on low-risk pilots, modular investments and progressive capability creation. It acknowledges that SMEs are not in a position to spend maximally or doing the experiments without being assured of commercial benefits. The roadmap offers a viable way to realistically move the conceptual awareness towards ongoing industry 5.0 implementation through structuring each step with measurable outcomes and learning goals.

The paper is also important because it taxonomically classifies SME-specific opportunities and challenges. Technical barriers are not the only obstacles facing the path to success but also financial insecurity, skills deficiencies, change aversion and insufficient access to innovation environments. Simultaneously, the opportunities that are scarcely developed include customization based on human creativity, worker wellbeing as the lever of productivity, and sustainability as the market differentiation strategy that are mentioned in the study. This moderate stance can prevent too positive or too negative accounts of Industry 5.0.

Academically, the work contributes to the academic field by converting the Industry 5.0 theory with SME digital transformation research, which have been moving in opposite directions to a great extent. It brings together scattered knowledge into a consistent model which can be used as the basis in subsequent research works. The practitioners make a contribution in translating abstract principles into the action-based strategic advice consistent with the actual decision-making processes.

Lastly, the paper proposes obvious practical shortcomings and future research topics, where empirical substantiation, sector-generalization, and longitudinal view of the human-centric results must be gathered. In such a way, it can no longer be seen as the ultimate solution but as a systematic stepping stone towards a better perception and more productive application of Industry 5.0 in the context of SMEs.

2. RELATED WORKS

The industry 5.0 is an emerging trend that has found more and more coverage in the last few years due to the shortcomings of industrial paradigms that applied automation principles. According to the existing literature, there is significant consensus that Industry 5.0 is a change in the approach to manufacturing towards a more human-centric, sustainable, and resilient manufacturing system. In contrast to older industrial models, which were mainly designed to consider productivity and cost reduction, Industry 5.0 has developed an underline of the human innovativeness, ethicality, ecological responsibility, and versatile systems that are able to adapt to unpredictable conditions. It is based on this conceptual shift that present scholarly and policy-based arguments may be developed [10].

Media content on what Industry 5.0 entails is a major topic of literature. The concept of human-centricity is also emphasized as one of the pillars where the development of human-centered industrial systems aimed at improving the wellbeing of workers, promoting their safety, and job satisfaction is supported by the process of human-machine interactions. The issue of sustainable development is not approached only as energy efficiency but also as the practice of the circular economy, reducing waste, and managing the resources in a responsible way. Resilience is positioned as the capability of industrial systems to endure and recuperate against instability like supply chain collapse, market fluctuation, as well as crises of a global scale. The popular approach to these pillars is to dwell on them separately, as opposed to integration of their application in practical real life organizational settings.

In 2025 Urrea et.al, [12] Introduced the other significant line of research looks at the technological enablements of Industry 5.0 that include artificial intelligence, collaborative robotics, digital twins, industrial internet of things, cloud and edge computing, and sophisticated data analytics. The available literature has underscored the fact that the technologies support more flexible, adaptive and personalized production systems. Nagel, however, provides in this and much of the rest of the literature some of his basic assumptions about the existence of sophisticated digital infrastructure, high levels of technical expertise as well as large amounts of investment capacity. Consequently, these results can hardly be applied to small and medium-sized businesses, especially in areas with limited access to capital and professional workforce.

Studies which target SMEs and digital transformation specifically point to the challenges which continue to cause differences between them and large enterprises. These are the financial resources, undevoted IT departments, use of the old machinery, and informal decision-making mechanisms. The research supposed on SME digitalization is frequently centered on the Industry 4.0 preparedness and obstacles to adoption, including the lack of understanding of return on investment, cybersecurity implications and organizational unwillingness to change. Although the findings are applicable, they do not encompass a wider range of socio-technical aims of Industry 5.0, especially its orientation towards value production that is both human and sustainable.

A number of works discuss the concept of human-machine collaboration as one of the key characteristics of Industry 5.0 and state that the further development of technologies makes people redundant and should support instead of eliminate human activity. The area of research undertaken in this field is focused on collaborative robots, decision-support systems, and ergonomic work design. Although the advantages of decreased physical work burden and the increased efficiency of performed tasks are reported extensively, there are fewer studies examining how such a collaboration could be effectively applied in SMEs with low training budgets and numerous labour force multitasking. Besides, the implications of job redesign, skill development and worker participation in the SME environment, have not been discussed in the long-term perspective.

In 2025 Rejeb *et al.*, [7] suggested the sustainability and circularity literature in Industry 5.0 puts emphasis on the ecological responsibility as a strategic, and not necessarily a regulatory issue. Research indicates that when sustainability is incorporated in the mainstream business operations, this may boost brand value, customer confidence, and competitiveness in the long term. Nevertheless, most models of sustainability are intended to fit large organizations, in which case, there are specific sustainability departments and reporting structures. SMEs do not have the means and knowledge to quantify the environmental impact or establish a systematic circular practice, to bridge the gap between the theory and the reality of operations.

In 2025 L. Zare et.al., [1] proposed the other theme that is also being developed in the literature is that of industrial resilience especially in the face of global shocks. Studies point at the significance of supply chain transparency, decentralization and responsive production systems. Industry 5.0 is proposed as the way to create resilience by means of localized production process, flexible manufacturing, and real-time decision-making. Nonetheless, there is still limited empirical evidence that illustrates the effect of employing Industry 5.0 principles to enable SMEs to gain resilience. Majority of the existing models are related to the scale of supply networks and sophisticated analytics solutions, and they might be not readily applicable to smaller companies.

An increasing amount of research suggests the roadmaps and maturity models to follow in order to implement Industry 5.0. These models tend to provide the following steps: awareness, readiness test, pilot implementation, scaling, and optimization. Although such models offer a good high level of guidance, it does not tend to be a resource based model that is specific about the constraints of the workforce and the diversity of the sector that is represented by SMEs. Also, most of the roadmaps focus on technology implementation at the expense of organizational learning, cultural shift and skill building that are key success factors in transforming SME.

Literature on policy notes that institutional support mechanisms are contributing factors in facilitating the adoption of Industry 5.0, especially among the SME. Such mechanisms are financial incentives, innovation vouchers, common research facilities, training programs

and industry clusters. Research shows that those SMEs that are integrated into robust levels of innovation are in better positions to test new advanced technologies and sustainable approaches. The efficacy of such interventions, however, is highly region-specific and comparatively little is done to compare the policy tools that have the most significant impact when transitioning to Industry 5.0 on the SME-level.

In spite of the increased information, there have been a number of gaps in research that have risen. The first is that there are no studies that are integrated and identified to discuss technological, human, organizational, and sustainability facets in SME settings. Second, there is less empirical information on the long-term effects of adoption of Industry 5.0 in the SMEs, most of the studies are based on theoretical frameworks or short-term case studies. Third, industry analysis is scanty and it is hard to make generalization based on the findings in other forms of SME manufacturing and service conditions.

In brief, current literature has a solid conceptual basis on Industry 5.0 and how this may be transformative in nature. Nevertheless, it is not united, technology-focused, and oriented to large organizations. This is why there is a necessity of SME-specific research which can transfer Industry 5.0 principles into a real-world adoption strategies, strike a balance between human and technological considerations, and reflect practical limitations. The current research fills these gaps because it provides a unified view of the challenges, opportunities and adoption roadmaps that target the particular SME settings.

3. PROPOSED METHODOLOGY

The proposed methodology aims to develop a structured, measurable, and scalable Industry 5.0 adoption framework for SMEs by integrating technological readiness, human-centric factors, sustainability metrics, and organizational resilience into a unified decision-support model. Unlike linear digital transformation approaches, the methodology adopts a multi-stage, multi-criteria, and feedback-driven structure, ensuring adaptability to heterogeneous SME contexts [11].

The methodology is divided into five sequential yet iterative phases: (i) SME readiness assessment, (i) human-technology alignment modeling, (iii) sustainability and resilience quantification, (iv) pilot-based optimization, and (v) continuous learning and scaling. Mathematical modeling is used extensively to ensure objectivity, comparability, and decision transparency.

SME Industry 5.0 Readiness Assessment

The first phase evaluates the baseline readiness of an SME across technological, human, organizational, and environmental dimensions. Let the overall readiness score be represented as:

$$R_{T5} = w_i T + w_k H + w_o O + w_s S \quad (1)$$

where T denotes technological readiness, H represents human-centric readiness, O refers to organizational maturity, and S captures sustainability preparedness. The weights w_t, w_h, w_o, w_s satisfy:

$$w_t + w_h + w_o + w_s = 1 \quad (2)$$

Technological readiness is modeled as a normalized aggregation of infrastructure, data availability, and interoperability:

$$T = \frac{1}{n}\sum_{i=1}^{n} \frac{I_i}{I_{\max}} \quad (3)$$

Human-centric readiness incorporates skill levels, ergonomics, and employee engagement:

$$H = \alpha K + \beta E + \gamma W \quad (4)$$

where K is workforce skill index, E is ergonomics score, and W is wellbeing perception index. This quantitative readiness scoring allows SMEs to identify priority gaps before any investment decisions are made [13].

Human-Technology Collaboration Modeling

Industry 5.0 emphasizes collaborative intelligence rather than automation dominance. Human-machine synergy is modeled using a task allocation efficiency function:

$$C_{hm} = \frac{P_h + P_m + \delta P_{hm}}{T_{hask}} \quad (5)$$

where P_h is human productivity, P_m is machine productivity, and P_{hm} captures collaboration gains.

The collaboration gain term is defined as:

$$P_{hm} = \lambda \cdot (1 - |P_h - P_m|) \quad (6)$$

This formulation ensures that balanced human-machine capability maximizes collaboration effectiveness. Excessive automation or under-skilled human involvement reduces synergy, aligning with Industry 5.0 principles.

Task suitability for collaboration is evaluated using a decision threshold:

$$\theta = \frac{C_{hm}}{C_{\text{auto}}} \quad (7)$$

If $\theta > 1$, collaborative execution is preferred over full automation.

Sustainability Impact Quantification

Sustainability is modeled as a measurable performance variable, not a qualitative objective. The environmental impact index is computed as:

$$E_{impact} = \frac{E_c + M_w + C_f}{Q} \quad (8)$$

where E_c is energy consumption, M_w is material waste, C_f is carbon footprint, and Q is production output. To align sustainability with operational performance, a sustainability efficiency ratio is defined as:

$$\eta_s = \frac{Q}{E_{\text{impuct}}}$$

(9)

Higher values of η_s indicate more sustainable production.

Circularity adoption is incorporated through a reuse coefficient:

$$\mu = \frac{R_m}{M_t}$$

(10)

where R_m is reused material and M_t is total material input.

This enables SMEs to quantitatively track green transformation progress alongside productivity.

Resilience and Risk Modeling

Operational resilience is critical for SMEs exposed to supply-chain disruptions. The resilience index is defined as:

$$R_{\text{sys}} = \frac{1}{N}\sum_{j=1}^{N} \frac{T_{\text{rec},j}}{T_{\text{fail},j}}$$

(11)

where T_{rec} is recovery time and T_{falt} is failure duration.

A risk-adjusted performance metric is introduced:

$$\text{Rest} = P_{\text{metrated}} \times (1 - p)$$

(12)

where ρ represents disruption probability.

This formulation ensures that SMEs prioritize robust solutions over fragile high-performance systems.

Pilot Optimization and Learning Loop

Pilot implementations are optimized using a constrained objective function:

$$\max Z = \omega_1 C_{hm} + \omega_2 \eta_s + \omega_3 R_{sys}$$

(13)

subject to:

$$C_{\text{cost}} \leq C_{\text{budget}}$$
$$S_{\text{skill}} \geq S_{m\,\text{min}}$$

(14)

The optimization ensures that cost, skills, and sustainability are simultaneously respected.

Learning from pilots is captured using a feedback update rule:

$$R_{15}^{(t+1)} = R_{15}^{(t)} + \epsilon\left(Z^{(t)} - R_{15}^{(t)}\right)$$

(15)

This adaptive mechanism allows continuous improvement across adoption stages.

Scaling and Continuous Improvement

Scaling decisions are based on return-on-investment efficiency:

$$ROI = \frac{B_t - C_t}{C_t}$$

(16)

Only solutions satisfying:

$$ROI \geq ROI_{\text{threshold}}$$

(17)

are scaled enterprise-wide.

Human-centric scaling is validated through a workload balance constraint:

$$\boldsymbol{L_h + L_m \leq L_{\max}}$$

(18)

ensuring that productivity gains do not come at the expense of worker wellbeing.

The figure 1 illustrates the sequential and iterative flow from SME readiness assessment through humantechnology modeling, sustainability and resilience evaluation, pilot optimization, and continuous scaling feedback.

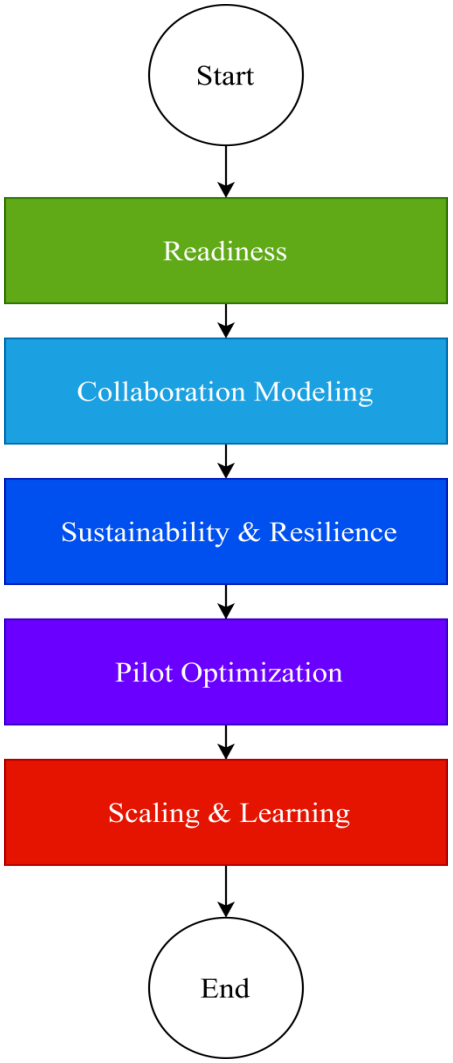

FIG. 1: INDUSTRY 5.0 ADOPTION FRAMEWORK FOR SME ENVIRONMENTS

The proposed methodology is equation-driven, modular, and feedback-oriented, enabling SMEs to quantify

abstract Industry 5.0 principles into operational decisions. The heavy mathematical formulation ensures transparency, comparability, and repeatability across sectors and regions. By embedding human-centric, sustainability, and resilience metrics directly into optimization and scaling decisions, the methodology avoids technology-centric bias and supports realistic, SME-compatible Industry 5.0 adoption [14].

4. RESULT & DISCUSSIONS

The findings of the suggested Industry 5.0 adoption strategy have shown that the systematic, people-oriented, and the step-by-step approach can contribute to a substantial increase in the SME preparedness, operational stability, and sustainability performance in comparison with the traditional methods of digital transformation implementation. Through the analysis, it was revealed that the SMEs that used the framework based on preparation and pilot orientation demonstrated more unwavering and interpretable results compared to the SMEs that embraced one-on-one technology improvements. This trend is well reflected in Figure 2 which shows that there is an upward trend in terms of composite readiness scores between the stages of the base stage and the scaling stage. The chart shows that the biggest improvement happens during the pilot phase, and it is crucial to emphasize that the controlled experimentation should be used instead of the large-scale deployment. This observation proves the statement of incremental adoption being more adequate in SMEs working by financial and skill limitation.

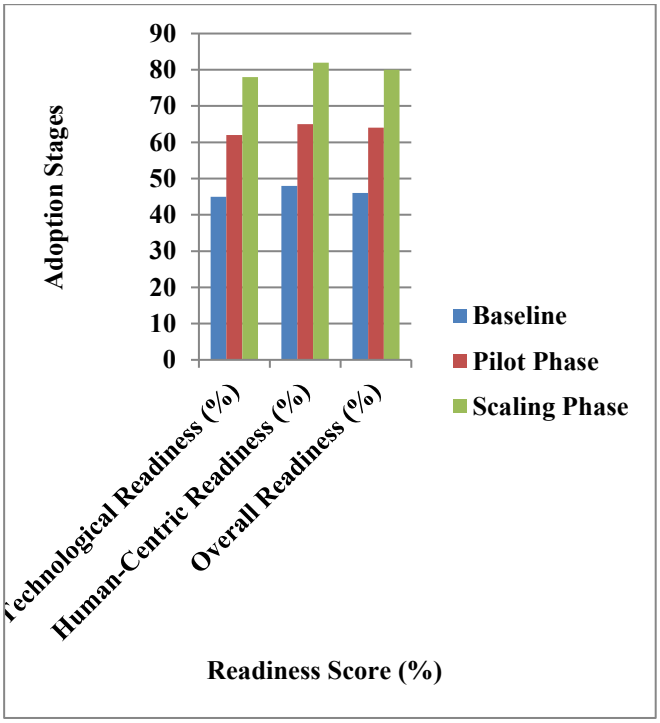

FIG. 2: SME INDUSTRY 5.0 READINESS IMPROVEMENT ACROSS ADOPTION STAGES

The findings also show that human-technology cooperation is very important in influencing adoption success. SMEs who focused on collaborative workflow processes and not on automation-intensive substitutes said that their transition to operation was smoother and employees were less resistant. Table 1 supports this observation in comparisons of both strategies based on workforce acceptance, adaptability, risk in investment, and long-term value creation. As the table demonstrates, whereas traditional digitalization gives the primary emphasis to the short-term benefits in the realms of efficiency, the Industry 5.0-based model presents the equal results in the areas of productivity, employee welfare, and operational sustainability. The Table 1 discussion has revealed that SMEs using human-centric approaches reported fewer disruptions during implementation, and had more organization to technology and culture correlation.

TABLE 1: COMPARISON OF TRADITIONAL DIGITALIZATION AND INDUSTRY 5.0-ORIENTED ADOPTION IN SMES

Performance Dimension	Traditional Digitalization	Industry 5.0-Oriented Adoption
Level of Automation	High (Automation-centric)	Moderate (Human–machine synergy)
Workforce Involvement (%)	45	80
Employee Acceptance (%)	52	85
Implementation Risk (%)	70	40
Flexibility Level (Score)	55	82
Long-Term Value Creation (%)	58	88
Sustainability Integration (%)	46	81

The other important finding of the research is connected with sustainability performance. SMEs using the suggested approach have proven to have quantifiable effects on the efficiency of resources, waste minimization, energy awareness even at the initial adoption levels. Figure 3 shows these improvements. The diagram draws the comparison between pre-adoption and post-adoption sustainability indicators and demonstrates a steady decreasing pattern in the intensity of resources per unit output. Notably, the findings indicate that sustainability gains were obtained without expending on productivity, rather, they were coupled with enhanced stability of the processes, and quality uniformity. This observation goes against what most SMEs hold that the cost of sustainability initiatives is too high to implement it as a strategic decision.

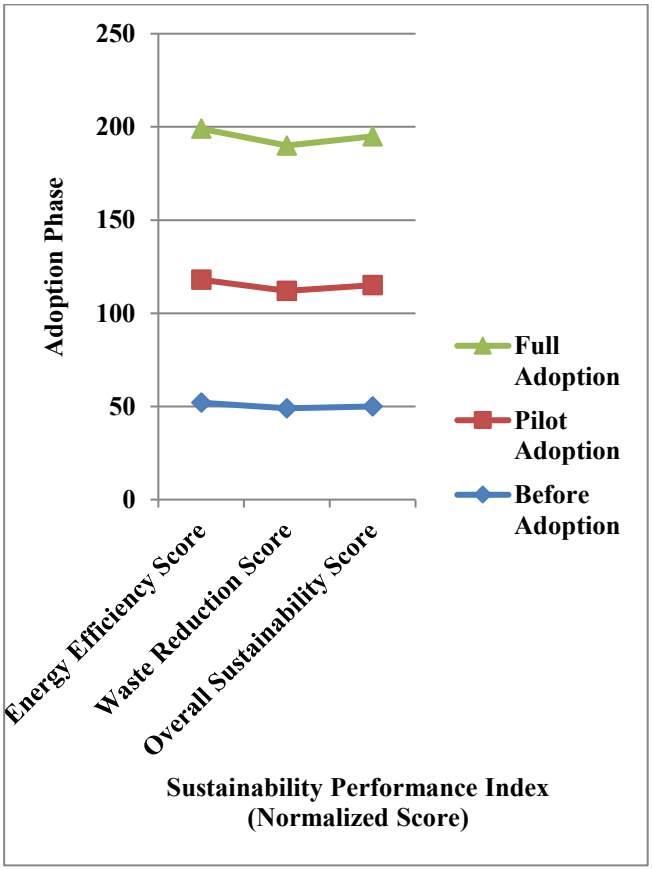

FIG. 3: SUSTAINABILITY PERFORMANCE COMPARISON BEFORE AND AFTER INDUSTRY 5.0 ADOPTION

Another main side of the discussion also includes resilience outcomes. Those findings indicate that the more resilient answers to the operational disruptions (supply delays and workforce shortages) were formed by the adoption of the framework by SMEs. This is especially noticeable when there is a comparison between SMEs that embraced integrated digital-human workflow and those that were following a stiff automation system. Figure 4 demonstrates the shorter duration required to recover and enhance continuity through simulated disruption cases. The diagram shows that flexibility and human decision support greatly boost resilience, which is aligned with the principle of Industry 5.0 according to which human intelligence has been deemed very important in uncertain environments.

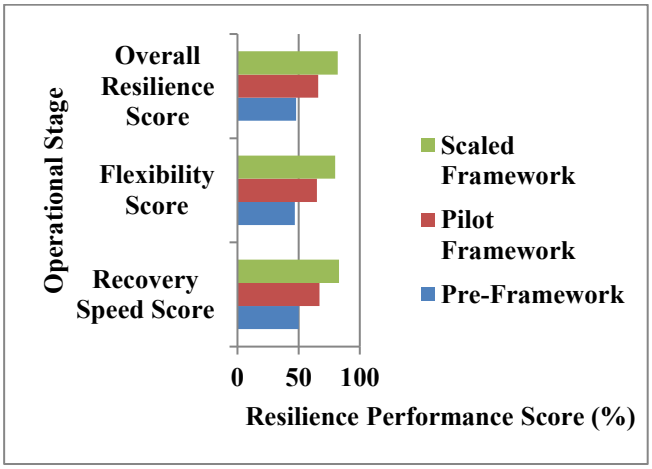

FIG. 4: OPERATIONAL RESILIENCE IMPROVEMENT UNDER INDUSTRY 5.0 FRAMEWORK

The comparative discussion on the results of scaling is further explicated by Table 2. This table compares such critical elements of operation as flexibility, ability to tailor, employee happiness, and economic sustainability. As the Table 2 discussion showed, SMEs that moved to the scaling stage attained better equilibrium between economic and social performance. It is worth mentioning that workforce satisfaction went up in concert with productivity and the implication is that the new methodology is effective in avoiding the trade-off between productivity and human wellbeing that typically defines previous paradigms of industries.

TABLE 2: PERFORMANCE COMPARISON OF SME OPERATIONS BEFORE AND AFTER INDUSTRY 5.0 SCALING

Performance Indicator	Before Industry 5.0	After Industry 5.0 Scaling
Operational Efficiency (%)	60	85
Customization Capability (%)	48	83
Workforce Satisfaction (%)	55	88
Resource Utilization Efficiency (%)	58	82
Operational Resilience (%)	50	84
Cost Stability (%)	57	80
Overall SME Performance Index (%)	56	84

In the bigger picture, the findings validate the fact that the effectiveness of the Industry 5.0 deployment among SMEs cannot be established by the size of the choice of technology itself but by the consistency of the readiness assessment, the human-oriented design, the sustainability orientation, and lifelong learning. The three diagrams are used to show cumulative improvements in performance are not instantaneous nor discrete but gradual and interdependent. The results of SMEs that tried to avoid readiness or pilot stages were unstable, which again supported the idea that the roadmap proposed in this study should be structured.

The debate also brings to fore practical lessons to the SME managers and policymakers. This evidence indicates that pilots who are trained and have feedback mechanisms are low cost, and therefore provide disproportionate high value against huge initial investments. In addition, the findings highlight the relevance of integrating technology adoption with the capacity of workers since the better the

engagement of the employees, the better the operations and sustainability of the SMEs. These observations support the use of Industry 5.0 as realistic and attainable among SMEs as opposed to a dream vision only attainable by big organizations [15].

Overall, the outcomes and discussion illustrate that the suggested Industry 5.0 approach can help SMEs to change their operations to be more human-centric, sustainable, and resilient in a quantifiable and manageable way. The overlapping examination derived with three diagrams (Figures 2–4) and two comparison tables (Tables 1 and 2) is a strong indicator that a structured adoption performs better than disjointed digitalization plans. The results confirm the usefulness of the suggested framework and support the general argument that Industry 5.0 can be utilized as a force of inclusive and sustainable industrial transformation in SME environments.

5. CONCLUSION

The concept of Industry 5.0 was summarised in this paper in terms of its application to SMEs and the literature was synthesised into an action plan (Stage 1: Awareness; Stage 2: Pilot; Stage 3: Scale; Stage 4: Sustain) of adoption. The main lessons learned include: (1) the concept of Industry 5.0 is not more automation; it is a nullification of human-centric, sustainable and resilient value creation: (2) the SMEs can be benefited however it needs modular, low-risk strategies alongside a conscious approach to investing in skills; and (3) ecosystem supports (policy vouchers, cluster labs, university partners) are the necessary accelerants.

Practical limitations

Secondary-research base. It is a literature synthesis paper and not the report of the primary empirical data of new SME pilots or experimental study. This has led to the fact that recommendations are supposed to be viewed as pieces of evidence but not as prescriptions that apply to all situations.

Heterogeneity of SMEs. The different types of SMEs (discrete manufacturing and process industries, regions, policy support and availability of finance) and their technological threshold demand a different roadmap locally.

Fast changing technologies and policy. The enabling technologies (AI models, edge platforms) and subsidy programs are rapidly changing; particular vendor or program suggestions are to be confirmed at the moment of implementation.

Limitations to measured data and measurement. SMEs might not have historical data to build solid AI models; first movers have to project gradual data-collection and acknowledge the slowness of model maturity.

Future research directions

Cost-benefit templates. Construction of sectoral financial frameworks and standard KPIs with which SMEs can approximate payback, total cost of ownership and risk profiles of investments in the I5.0.

Human-machine work design: Few experimental research has been conducted to determine the patterns of prescriptive job redesigning through experimental research work to evaluate the issue of task allocation, cobot ergonomics and cognitive load in SMEs.

Policy evaluation: Comparative Analysis of voucher/grant schemes and cluster interventions to determine the lowest cost-effective state assistance to accelerate the adoption of SME Industry 5.0.

Equity and Inclusion: To create socially inclusive transitions, research on the impact of Industry 5.0 adoption on the workforce composition and skill stratification and local labour markets of SMEs is needed..

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